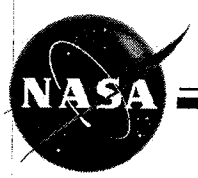
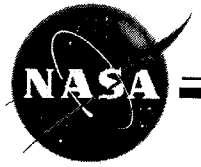


Characterizing Digital Camera Systems: A Prelude to Data Standards

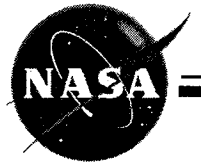
Robert Ryan
Lockheed Martin Space Operations - Stennis Programs
John C. Stennis Space Center

April 24, 2002



Outline

- Digital Imaging Systems
- Specifying a Digital Imagery Product
- Characterization of Data Acquisition Systems
- Summary



Introduction

- Advanced large array digital imaging systems are routinely being used
- Digital imagery guidelines are being developed by ASPRS and ISPRS
- Guidelines and standards are of little use without standardized characterization methods

Digital Imaging Systems

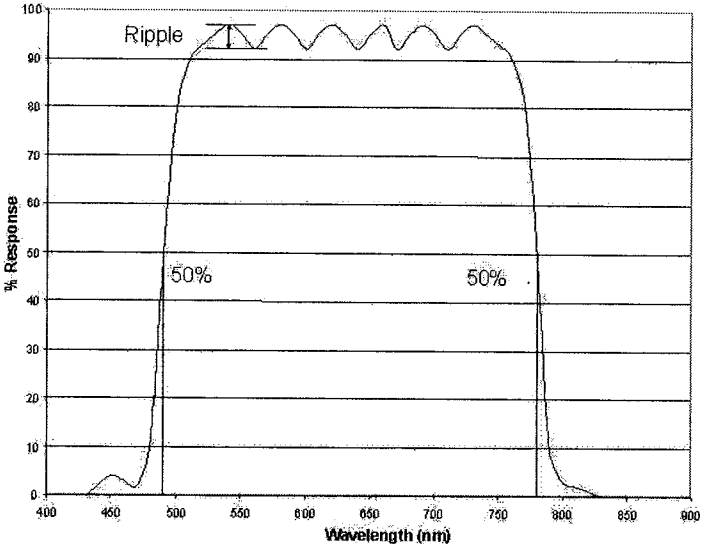
Both pushbroom line scanners and advanced framing direct digital imaging systems are being developed for airborne and spaceborne systems

- IKONOS
- QuickBird
- Kodak 4kx4k
- LH Systems
- Z/I
- Others

Specifying a Digital Imagery Product

- **After the acquisition area and window have been selected the following properties need to be defined**
  - Spectral
    - Panchromatic or Multispectral (number of bands)
    - Band-to-Band Registration
  - Spatial Resolution
    - Spatial/Frequency Domain
    - Edge response
    - Signal-to-Noise Ratio
  - Radiometry
    - Linearity
    - Cosmetic/Relative
    - Absolute
  - Geolocational Accuracy
- **The ASPRS Digital Imagery Guideline addresses many of these items**

Spectral Characteristics: Bands

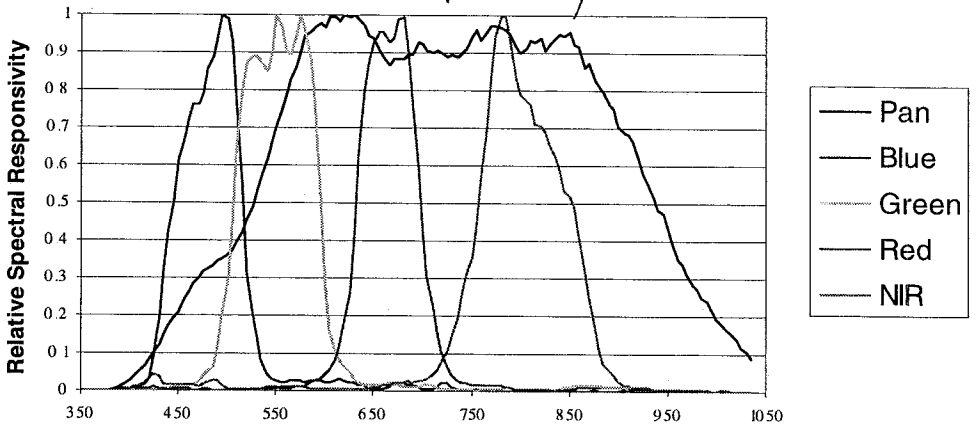


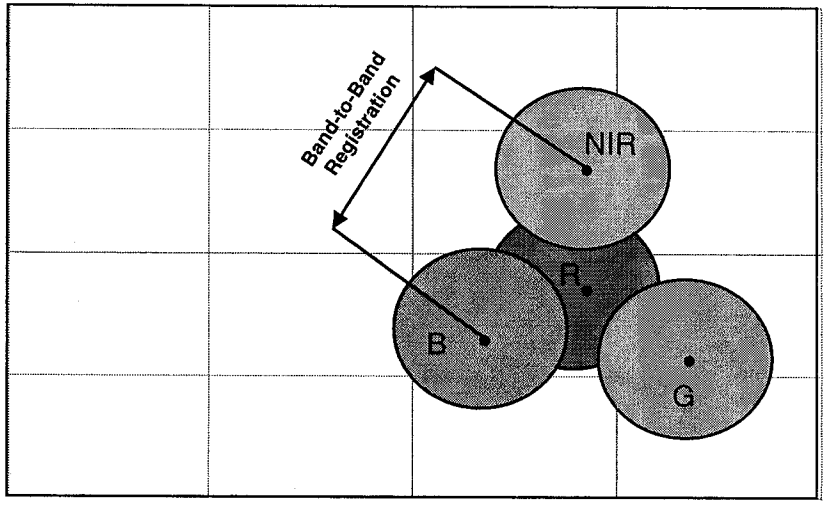
$\lambda_{cut\text{-}on}$ 50% (spectral response) ± 10 nm
Slope @ 50% > 1% / nm

$\lambda_{cut\text{-}off}$ 50% (spectral response) ± 1(
Slope @ 50% > 1% / nm

System spectral response

IKONOS Relative Spectral Response





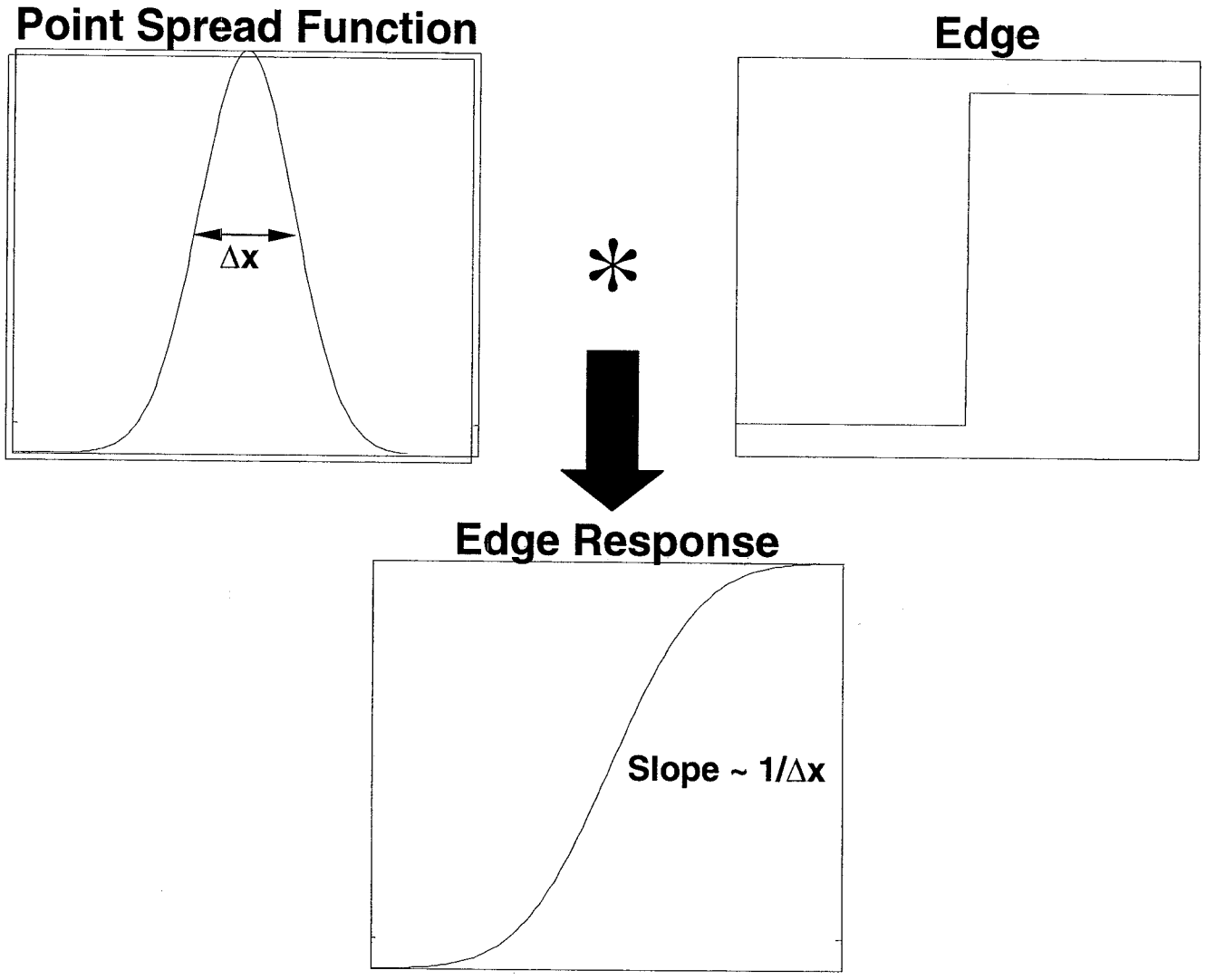
Band-to-band registration

Spatial Resolution: Spatial/Frequency Domain

- **Most specifications are written in terms of MTF as a function of spatial frequency**
  - Dominant parameter is typically MTF @ Nyquist frequency
  - Nyquist frequency depends on GSD
    - Nyquist frequency = 1/(2*GSD)
  - MTF at Nyquist is a measure of aliasing
  - MTF measurements at Nyquist are difficult to estimate in-flight
- **Edge Response is more intuitive**
  - RER (Relative Edge Response)
  - Ringing

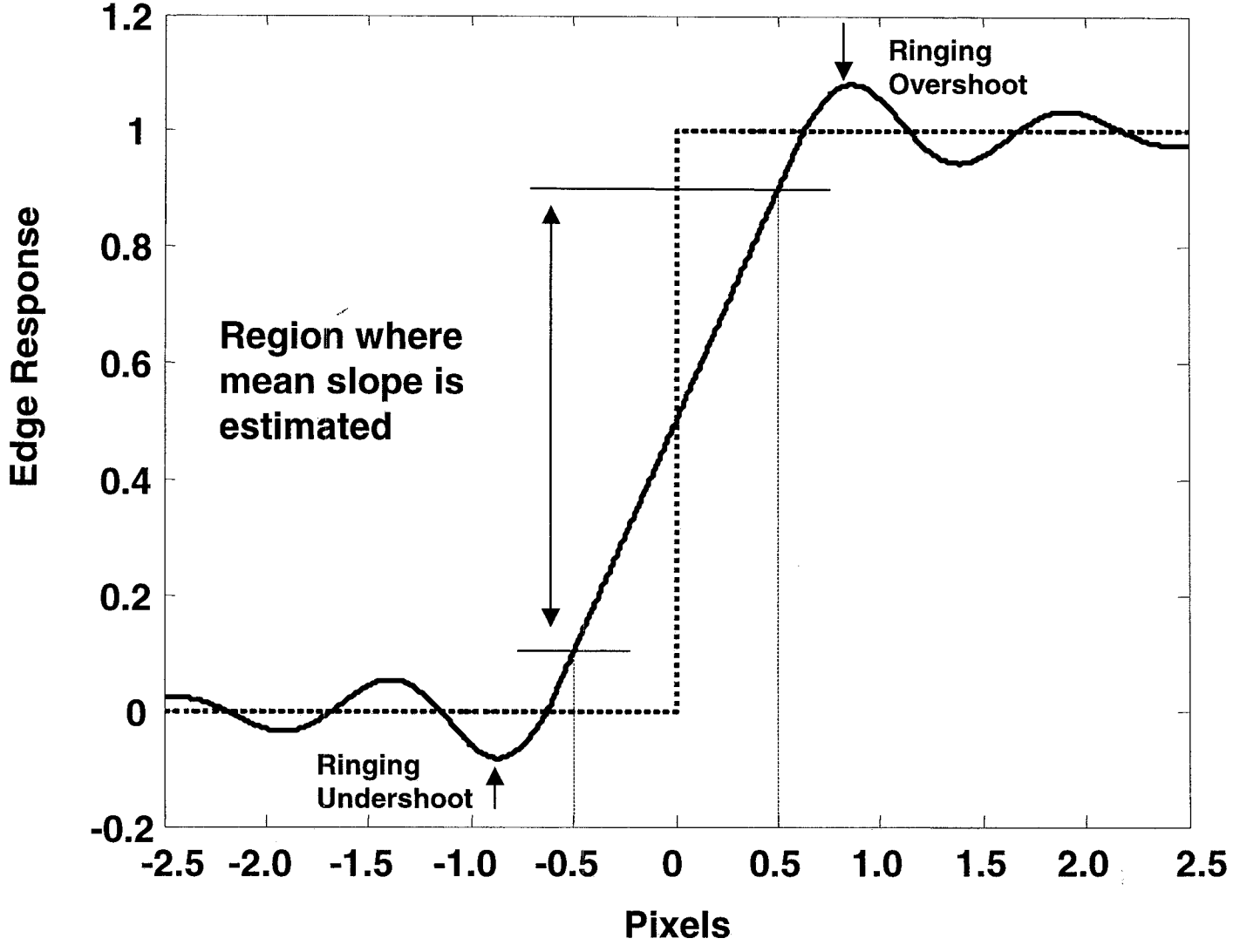
Spatial Resolution: Edge Response

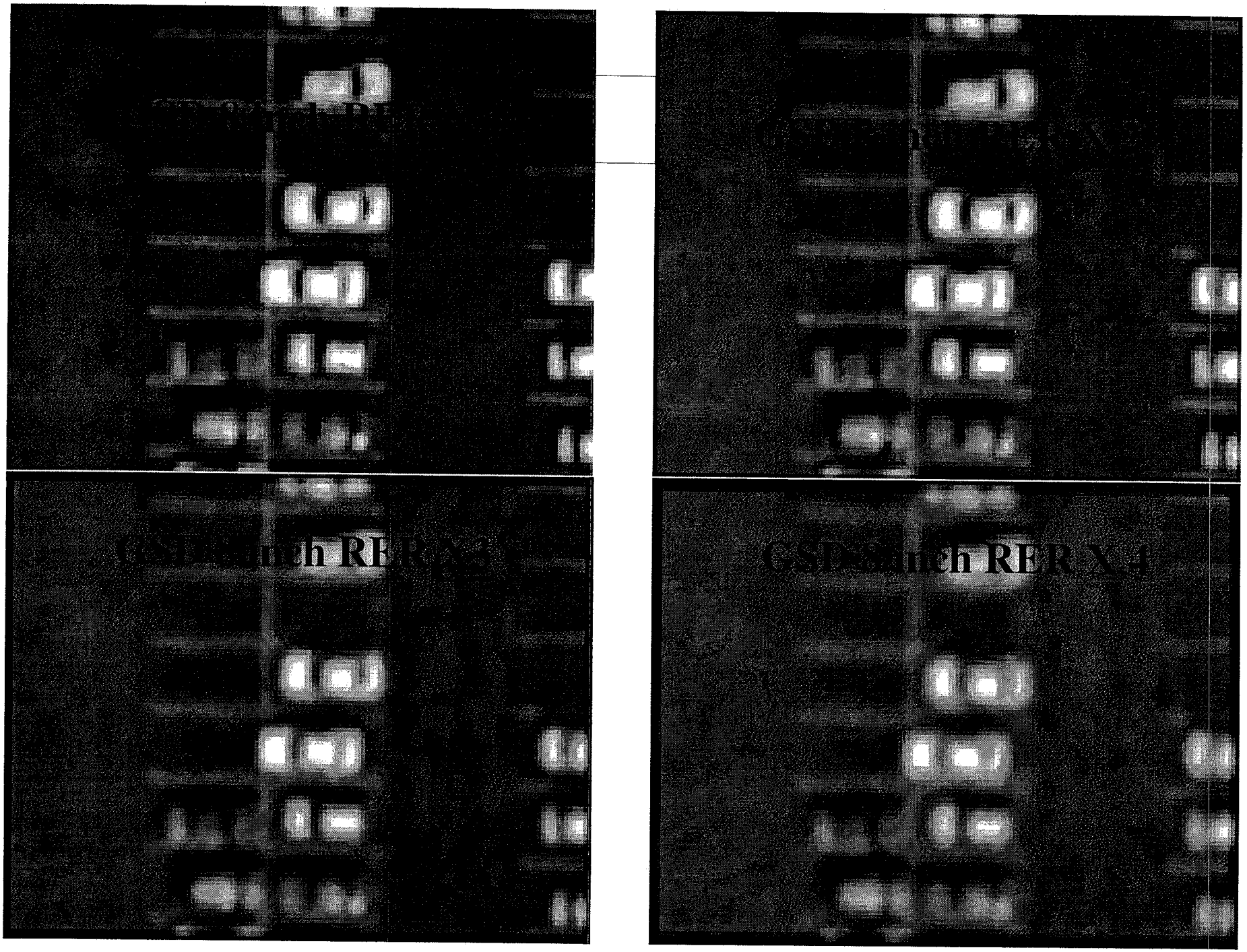
Spatial Domain



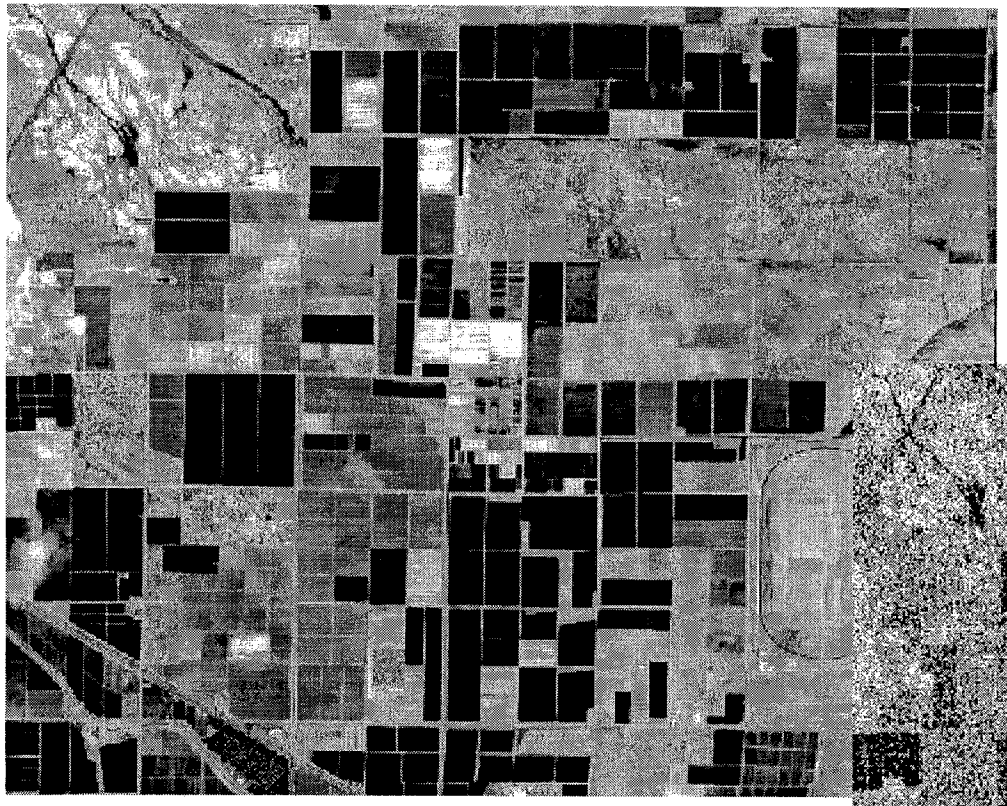
Steepness of edge response effects spatial resolution

Spatial Resolution: Relative Edge Response



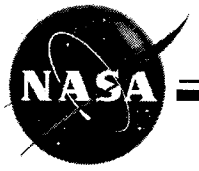

GsDeutsch RBRX4
GsDeutsch RBRX4

Spatial Resolution: SNR



← Original Maricopa IKONOS Imagery
SNR ~ 100

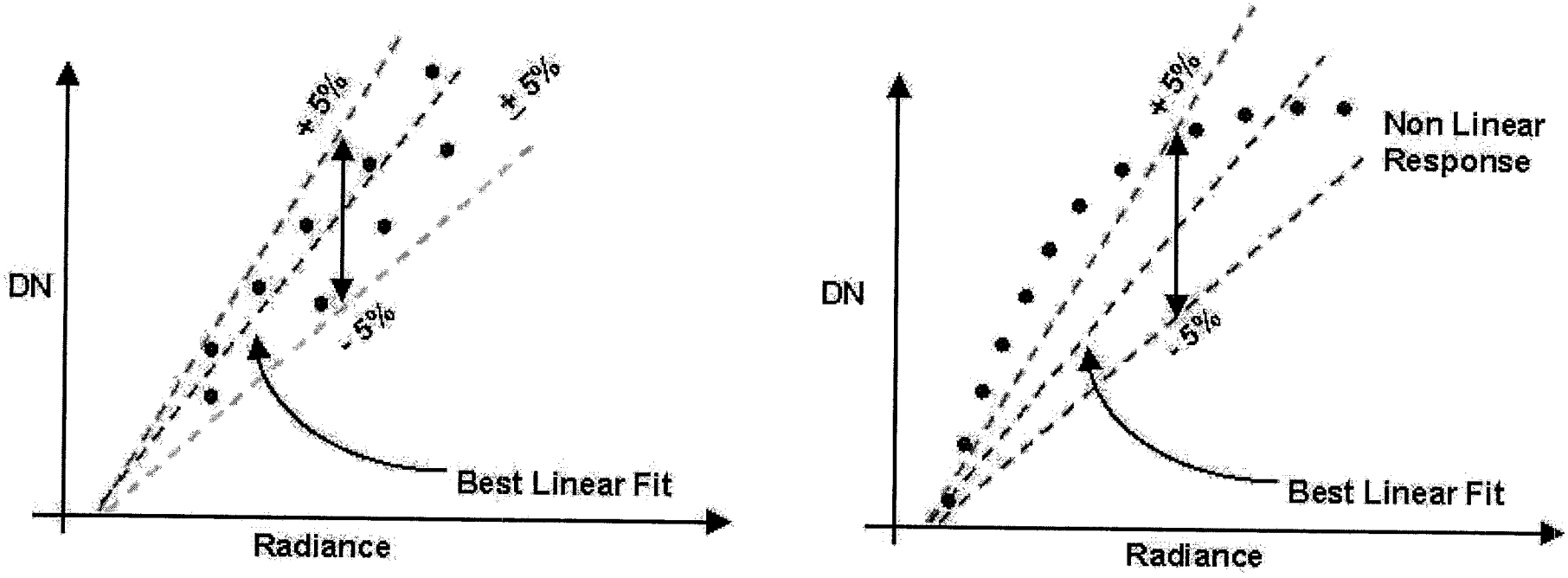
Maricopa IKONOS Imagery with Noise Added →
SNR ~ 2



Radiometry Specification

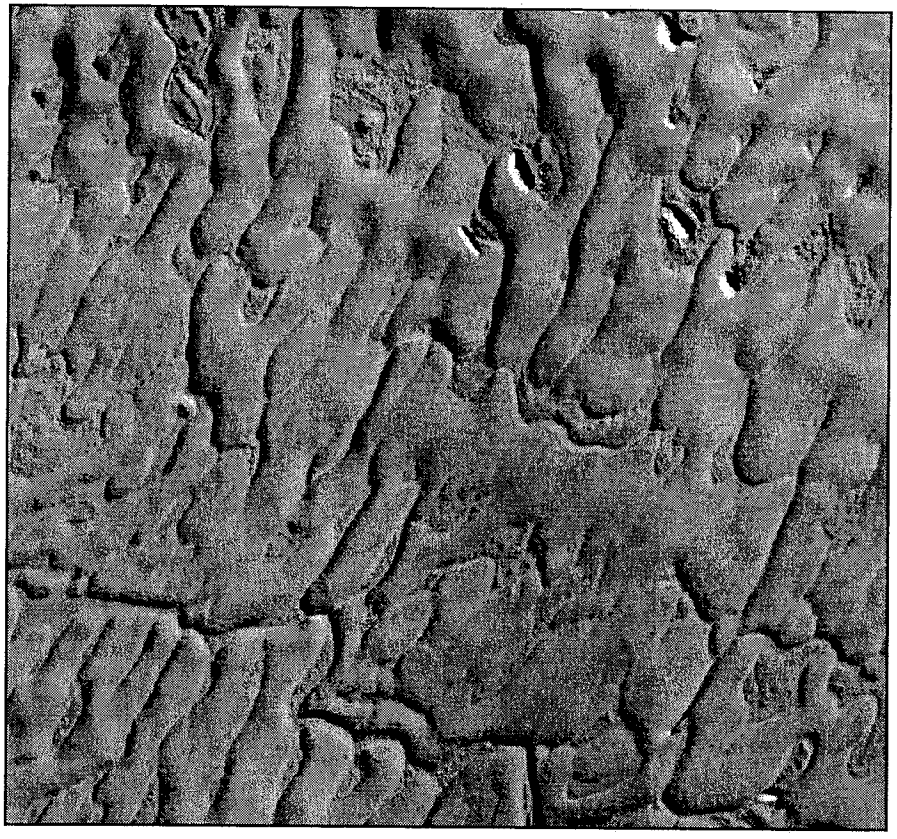
- **Three Types**
  - Linearity
  - Relative
    - Pixel-to-Pixel
    - Band-to-Band
  - Absolute

Radiometry: Linearity



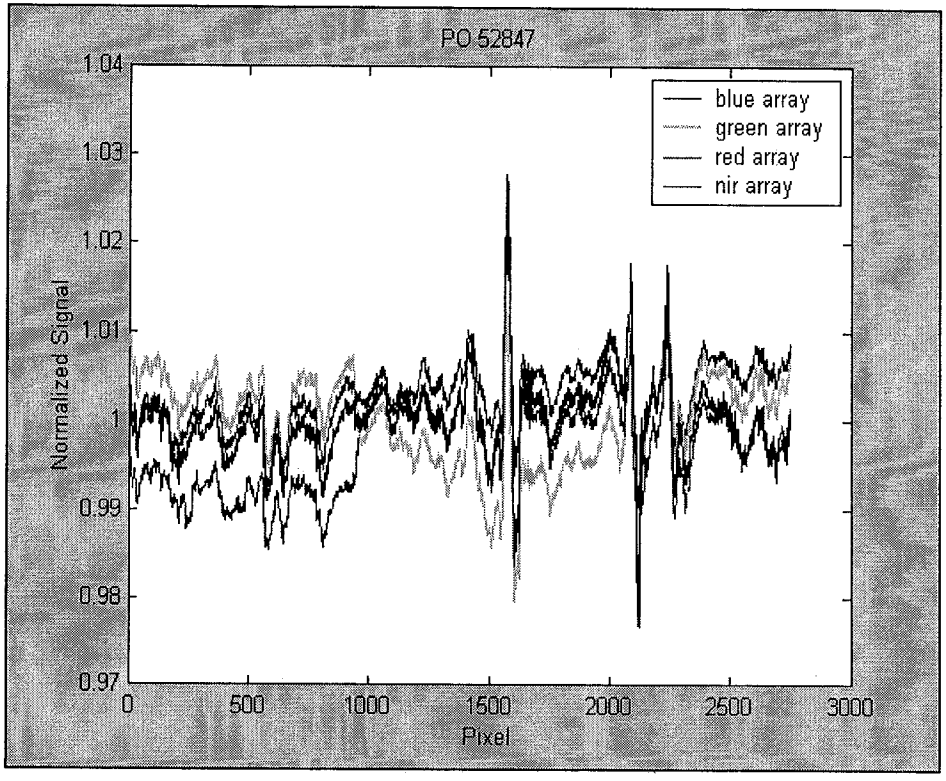
Linear and non-linear response to input radiance

Radiometry: Relative



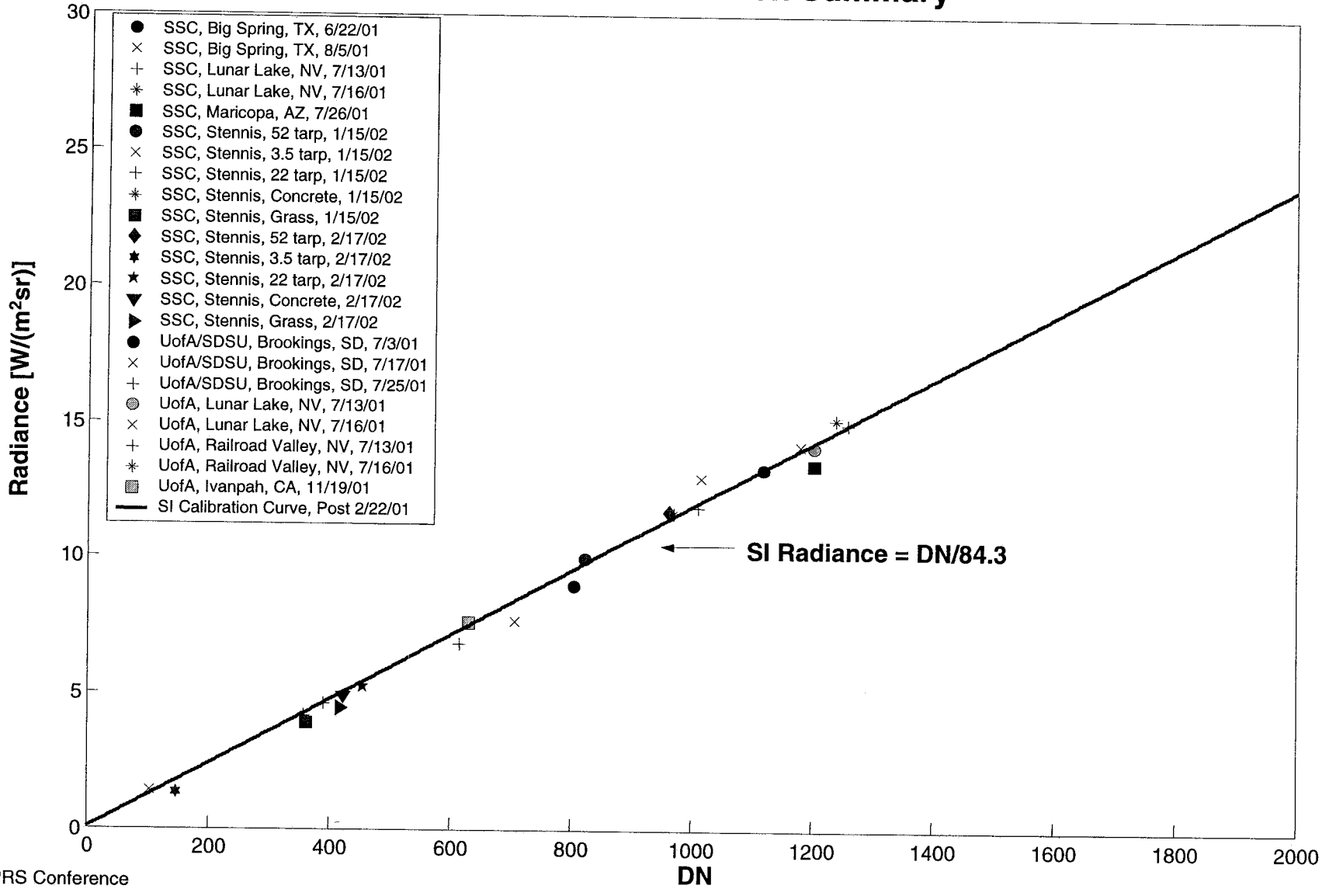
IKONOS Image of Antarctica – RGB, POID 52847

Normalized Average Row Values for Antarctica



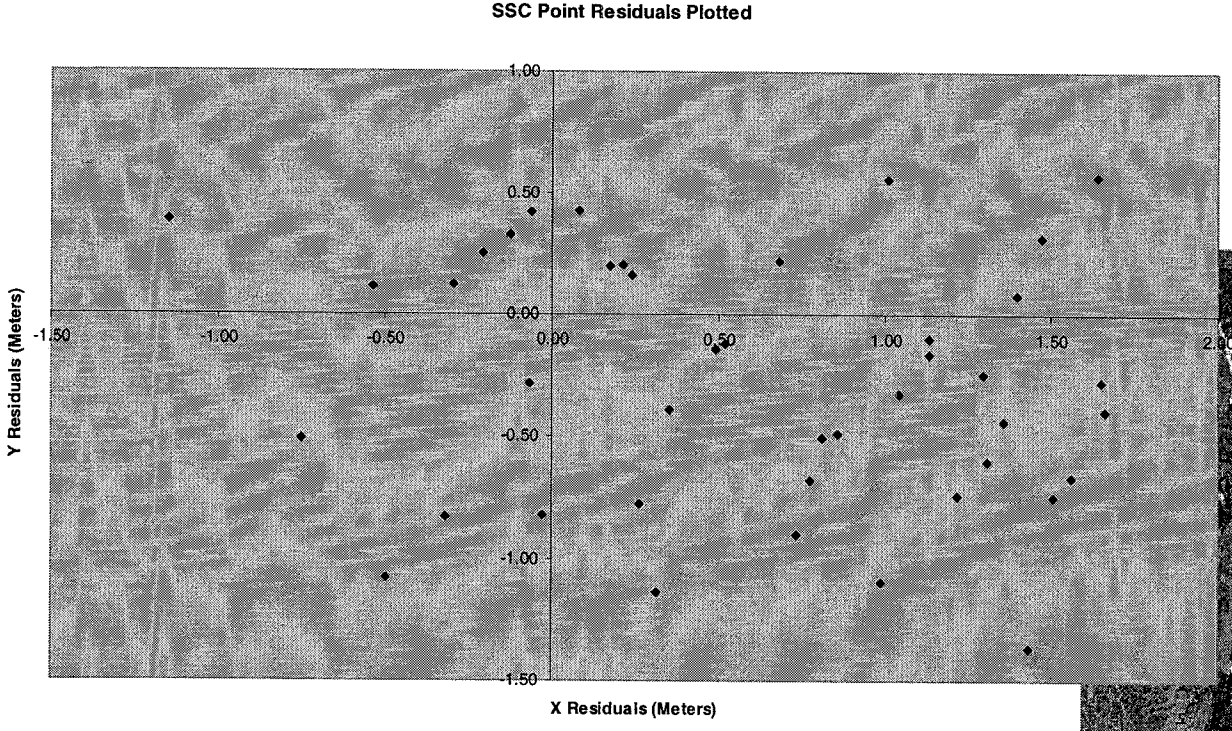
Radiometry: Absolute

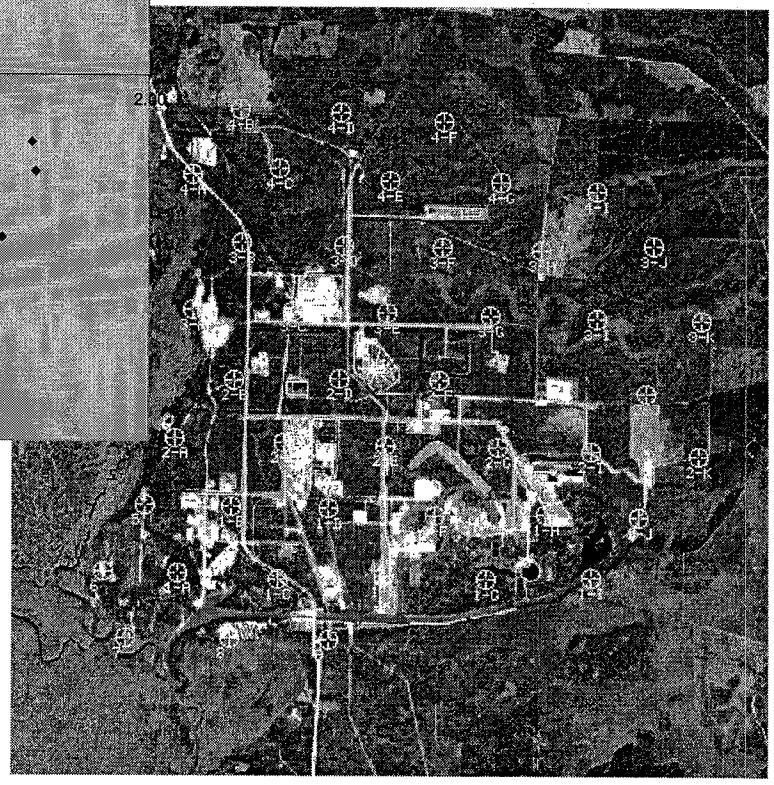
NIR Band Calibration Summary



Geolocational Accuracy

- **Geolocation of Pixels**





Data Product Specifications

- Spectral
- Spatial Resolution
- Radiometry
- Geometry

Laboratory vs. In-Flight: Spectral

Item	Specification	Verification	
		Lab	Functional (In-Flight)
Spectral Band Information	– Spectral band pass (Blue) 450-515 nm	X	
	– Spectral band pass (Green) 525-605 nm	X	
	– Spectral band pass (Red) 630-690 nm	X	
	– Spectral band pass (NIR) 750-860 nm	X	
Spectral Band Pass Accuracy	– Band edge points at 50% peak response shall be within ± 15 nm of the normal values	X	
	– Slope through the 50% point shall be at least 15% per 20 nm	X	
	– Out-of-band filter response must be less than 5% of the total integrated transmittance within 5% of the transmission points of the band	X	

Laboratory vs. In-Flight: Spatial

Item	Specification	Verification	
		Lab	Functional (In-Flight)
Spatial Resolution and Image Quality (at all field angles)	At zero spatial frequency, for all spectral bands, the SNR will be greater than 70 for a Lambertian surface with 20% reflectance, illuminated at solar zenith angle of 30 degrees	X	X

Laboratory vs. In-Flight: Radiometry

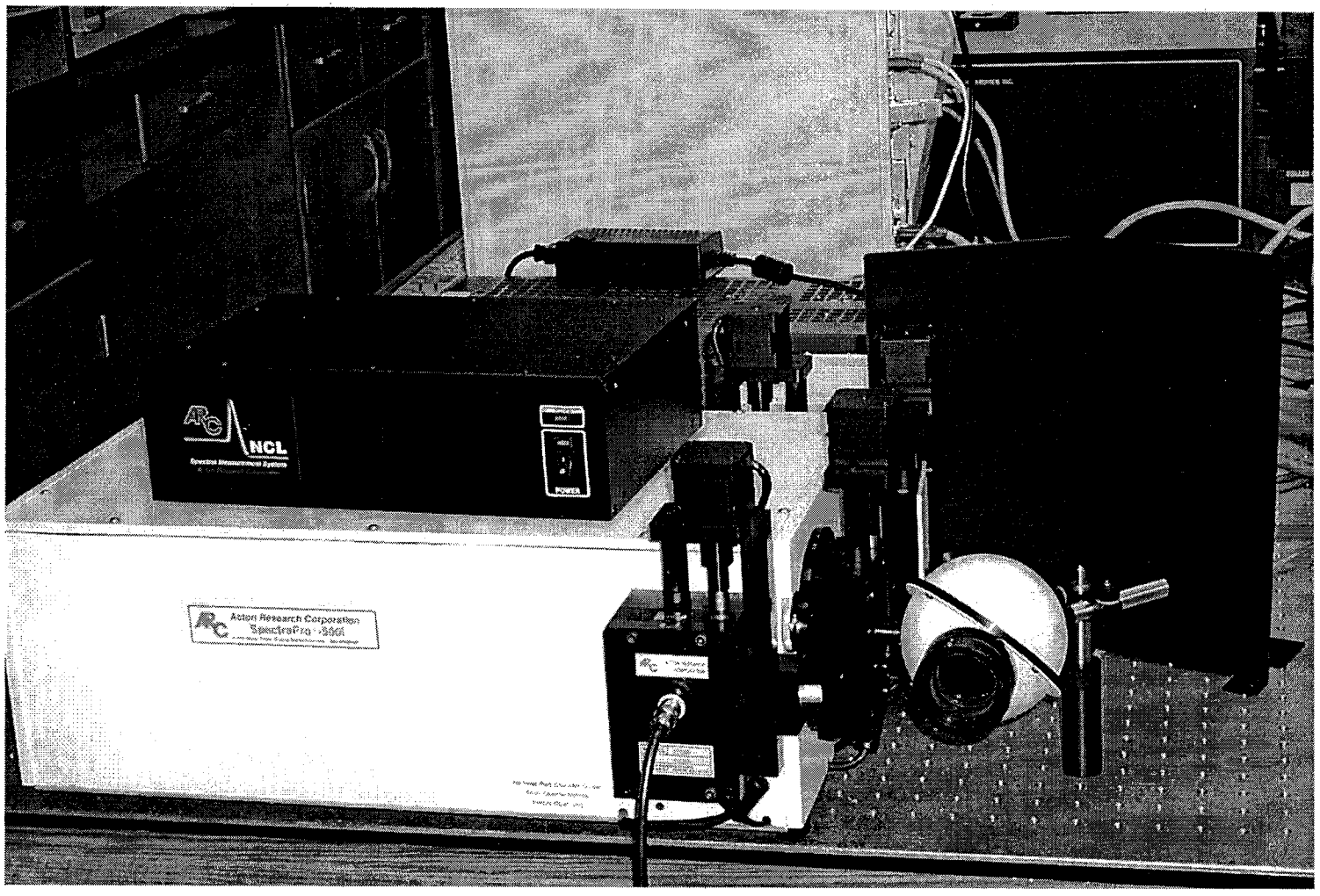
Item	Specification	Verification	
		Lab	Functional (In-Flight)
Radiometric Accuracy Stability	– Absolute radiometric accuracy to with ± 10%	*	X
	– Relative radiometric accuracy to with ± 5%	*	X
	– Linearity to within ± 5% of full scale exposure over the entire imaging exposure dynamic range	X	X
	– Requirements on banding, streaking, failed and non-calibrated detectors: 99.5% of all the detectors should be within ± 5% or ± 1 DN of the mean dark counts of all focal plane array detectors; 99.5% of all the detectors should be within ± 5% of the gain coefficients of all focal plane array detectors	X	X
Radiometric Quanitization	8-bits per spectral channel	X	X

Laboratory vs. In-Flight: Geometric

Item	Specification	Verification	
		Lab	Functional (In-Flight)
Absolute Geolocational Accuracy	Frame center point coordinate referenced to ± 100 meters in metadata listing		X

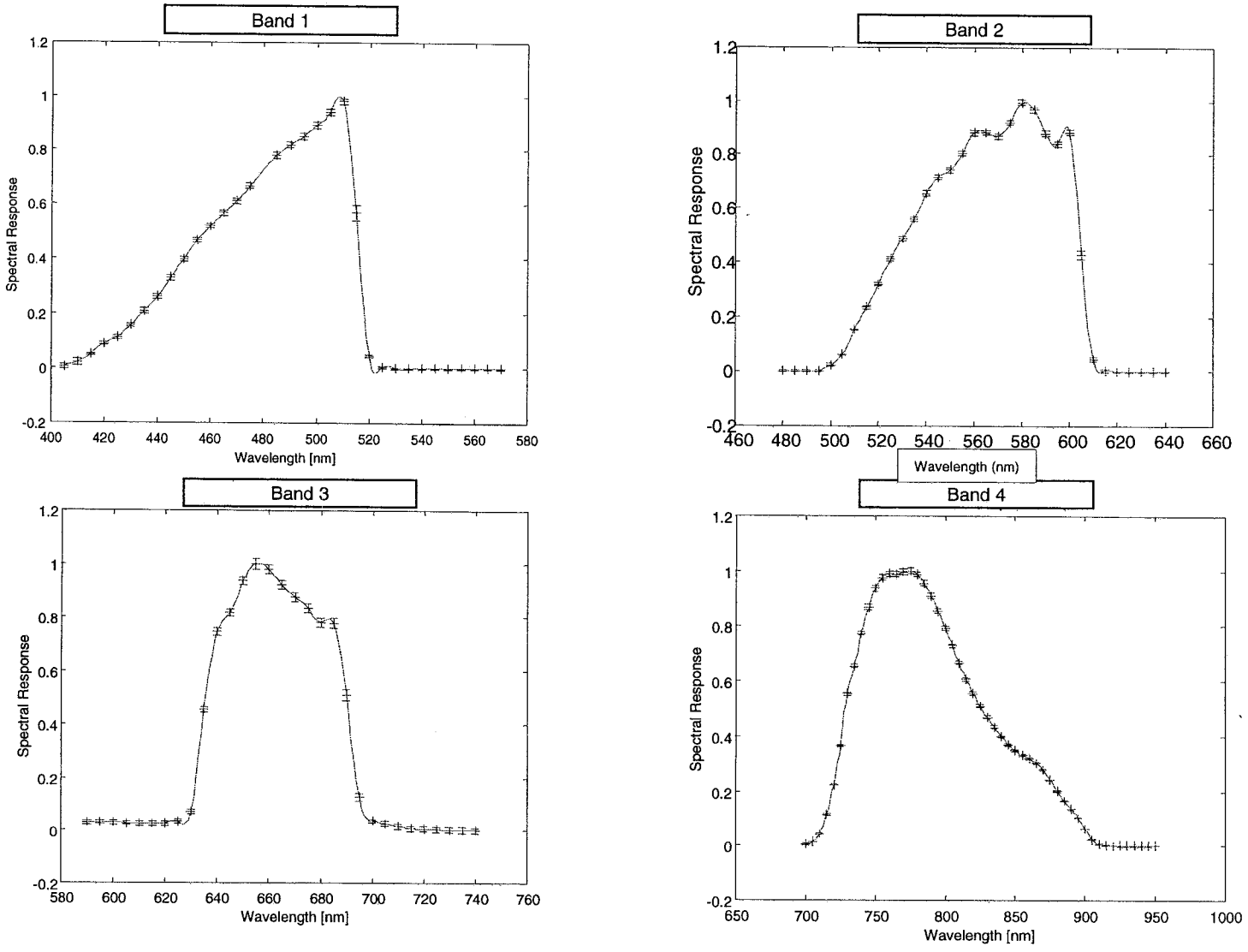
Laboratory Characterization

Spectral Characterization



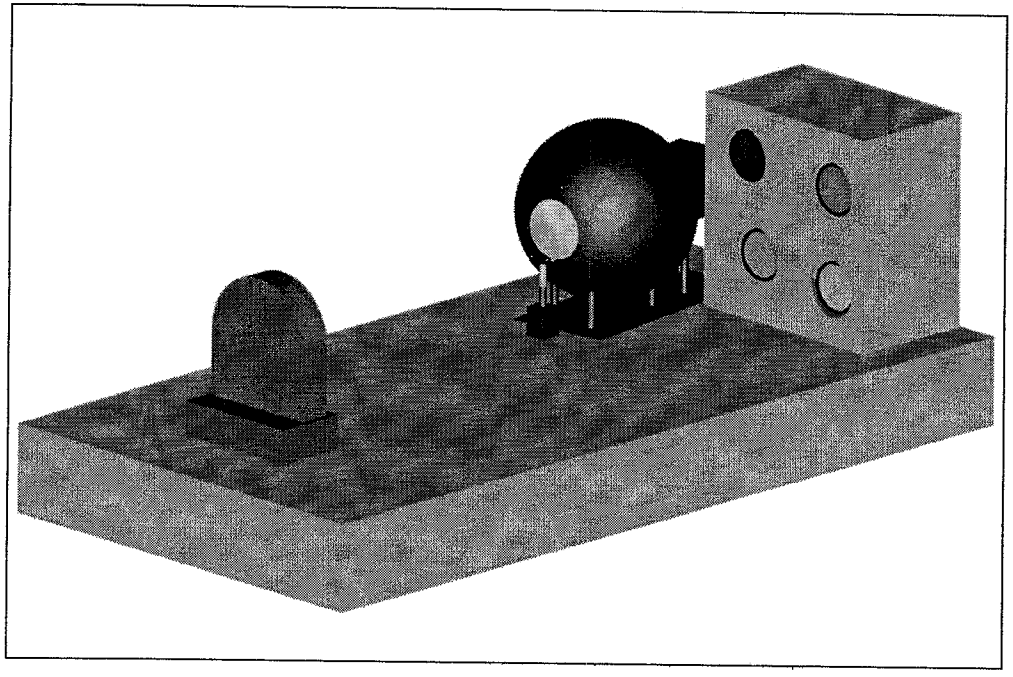
Test setup for overall system spectral response

Spectral Characterization



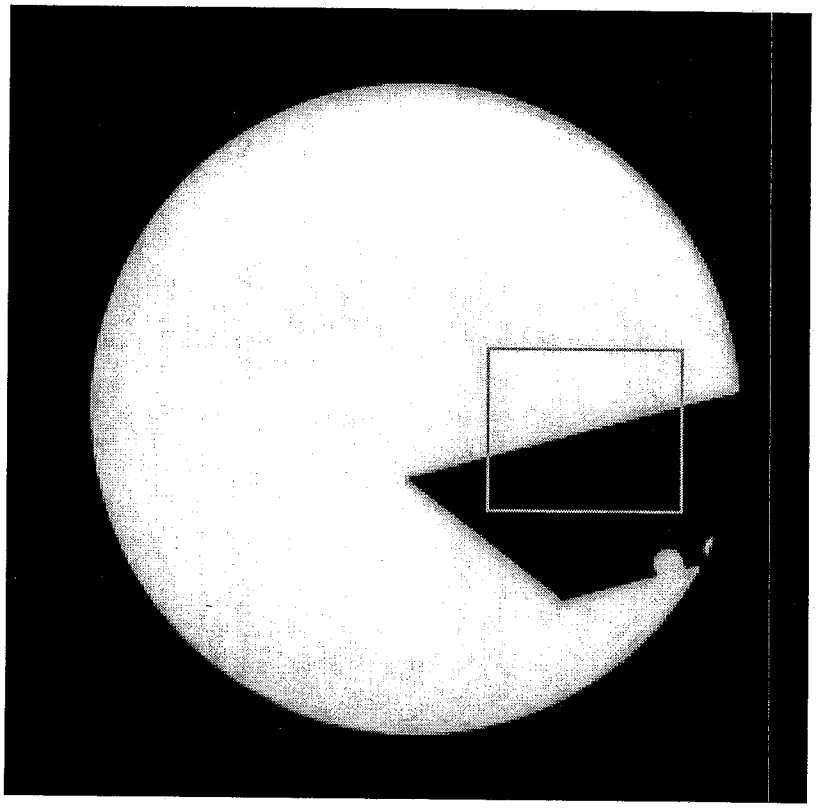
Normalized spectral response functions. Measured points are shown with error bars. Lines show spline interpolation between the points.

Spatial Characterization

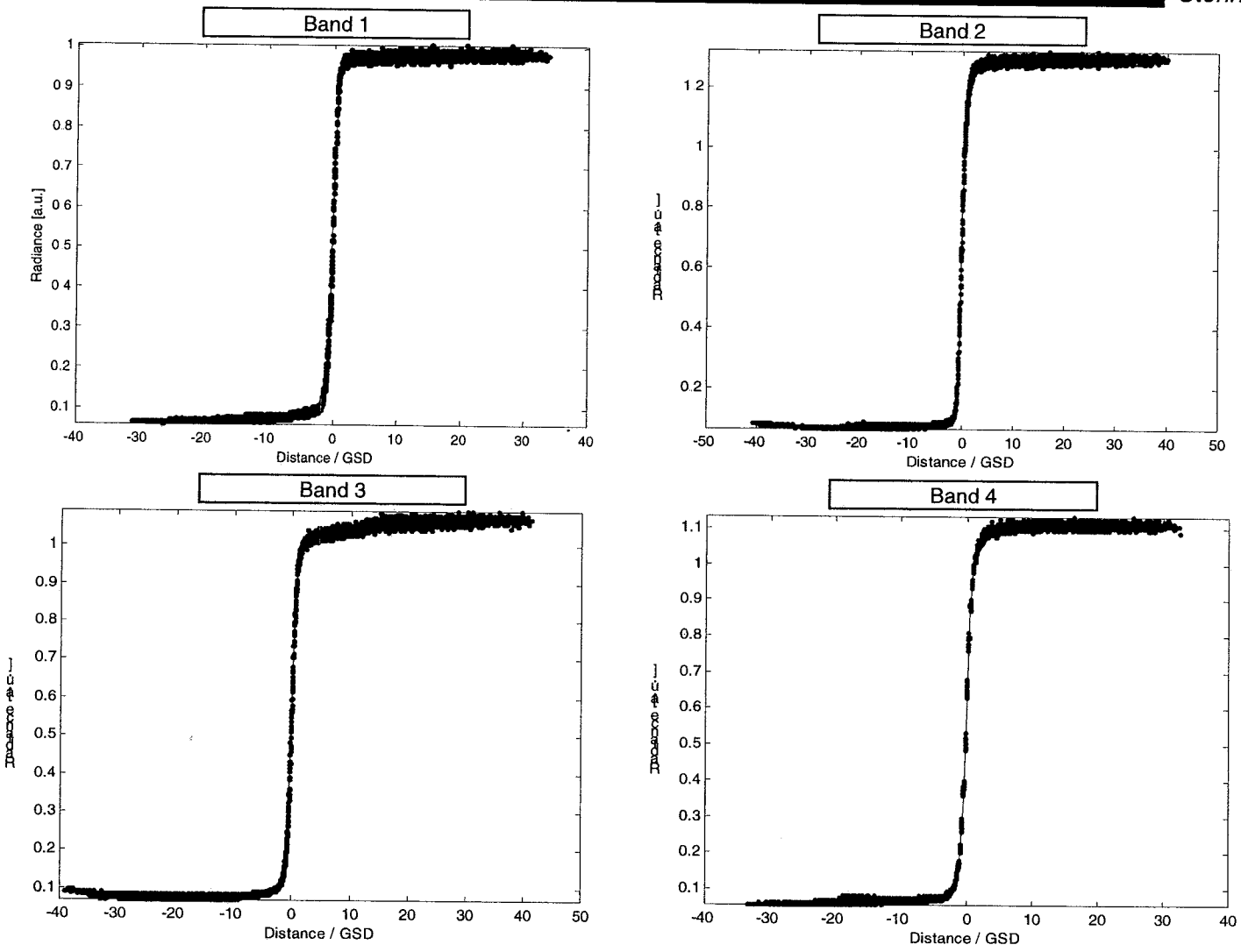


MTF test setup looking at the edge target in a collimator

Fragment of a Blue-band image from tests of spatial resolution of the ADAR 5500 SN4 sensor

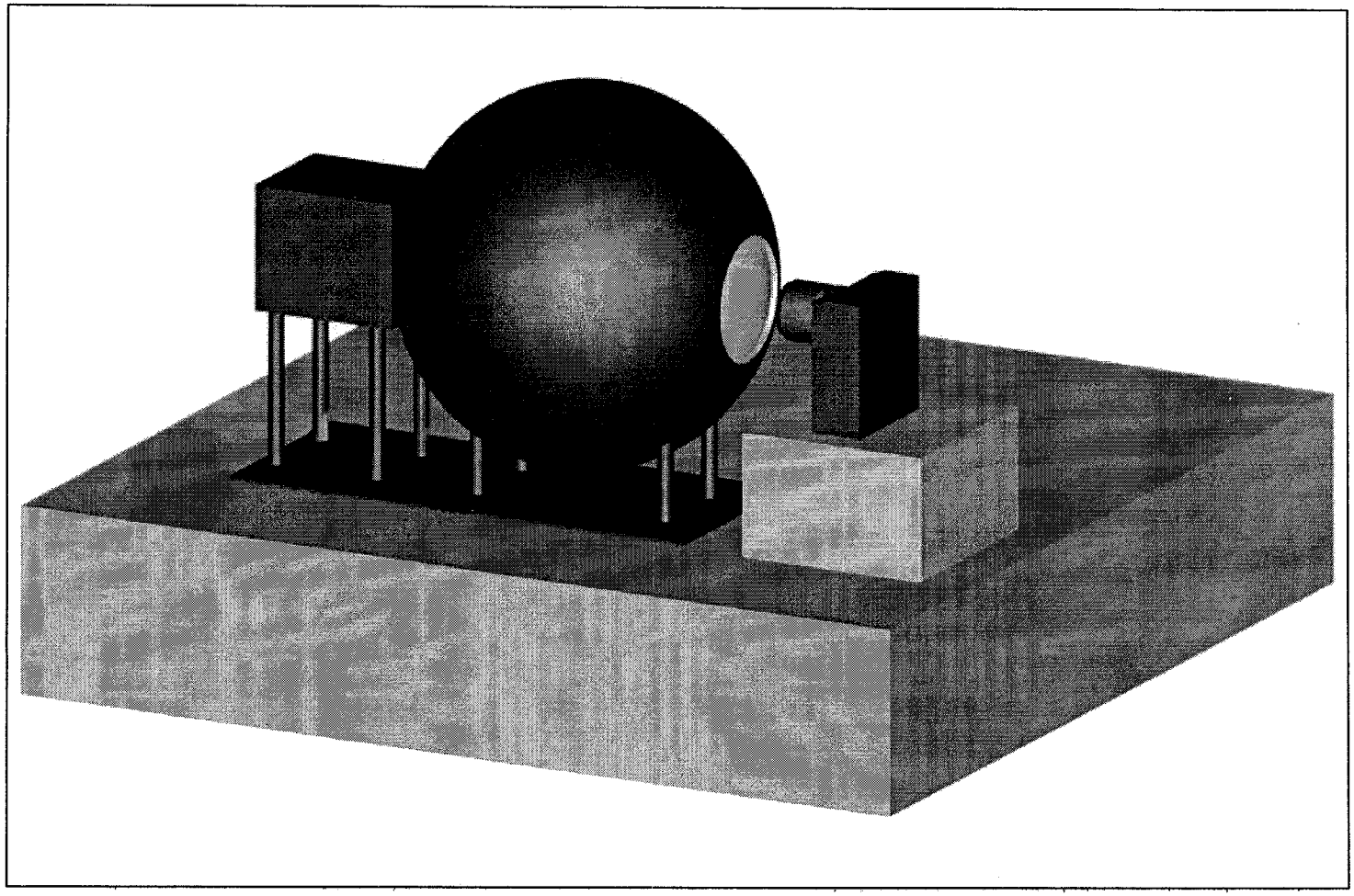


Spatial Characterization



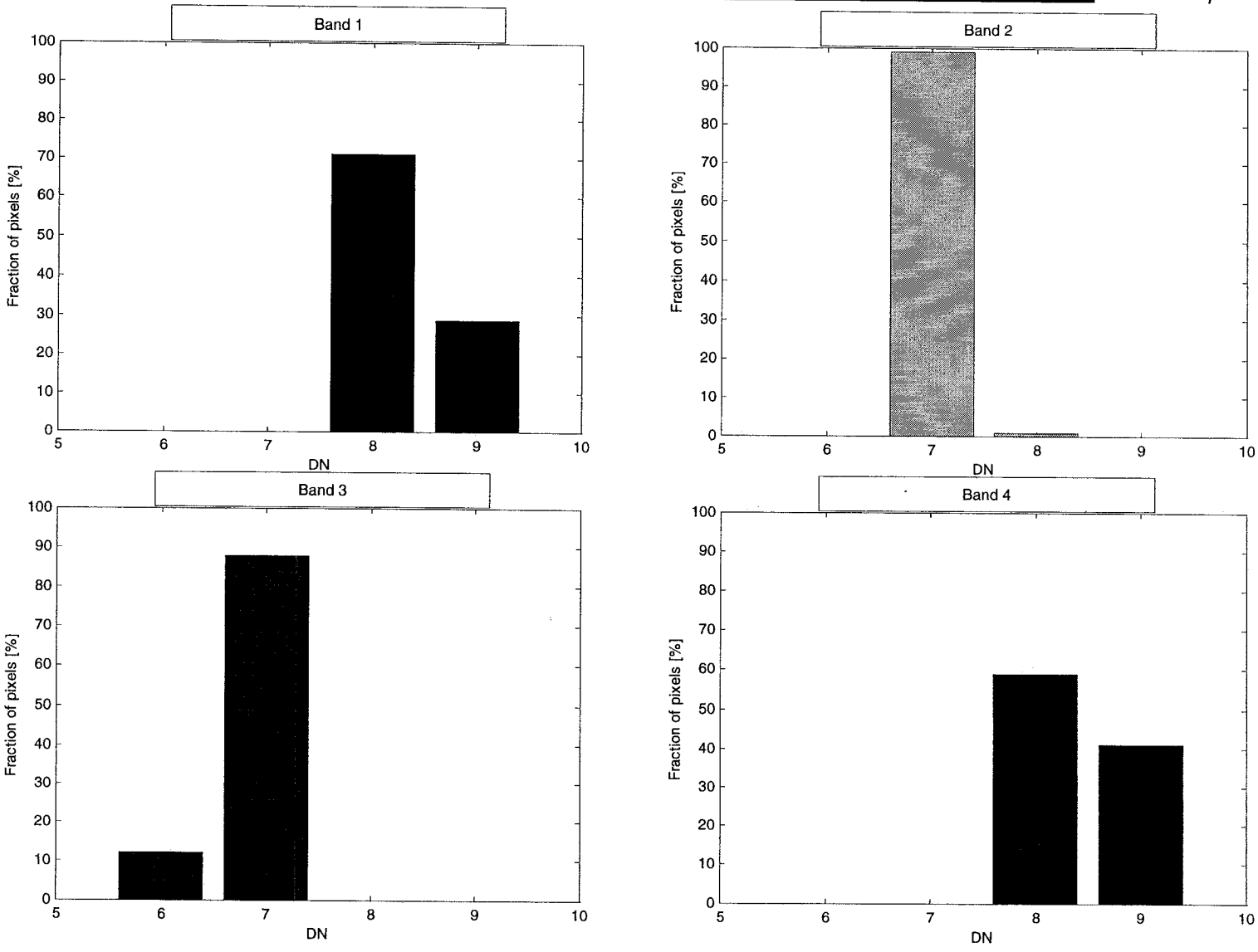
Examples of edge response functions. Measured points are shown with circles. Solid lines show the overall fitted functions.

Radiometric Characterization



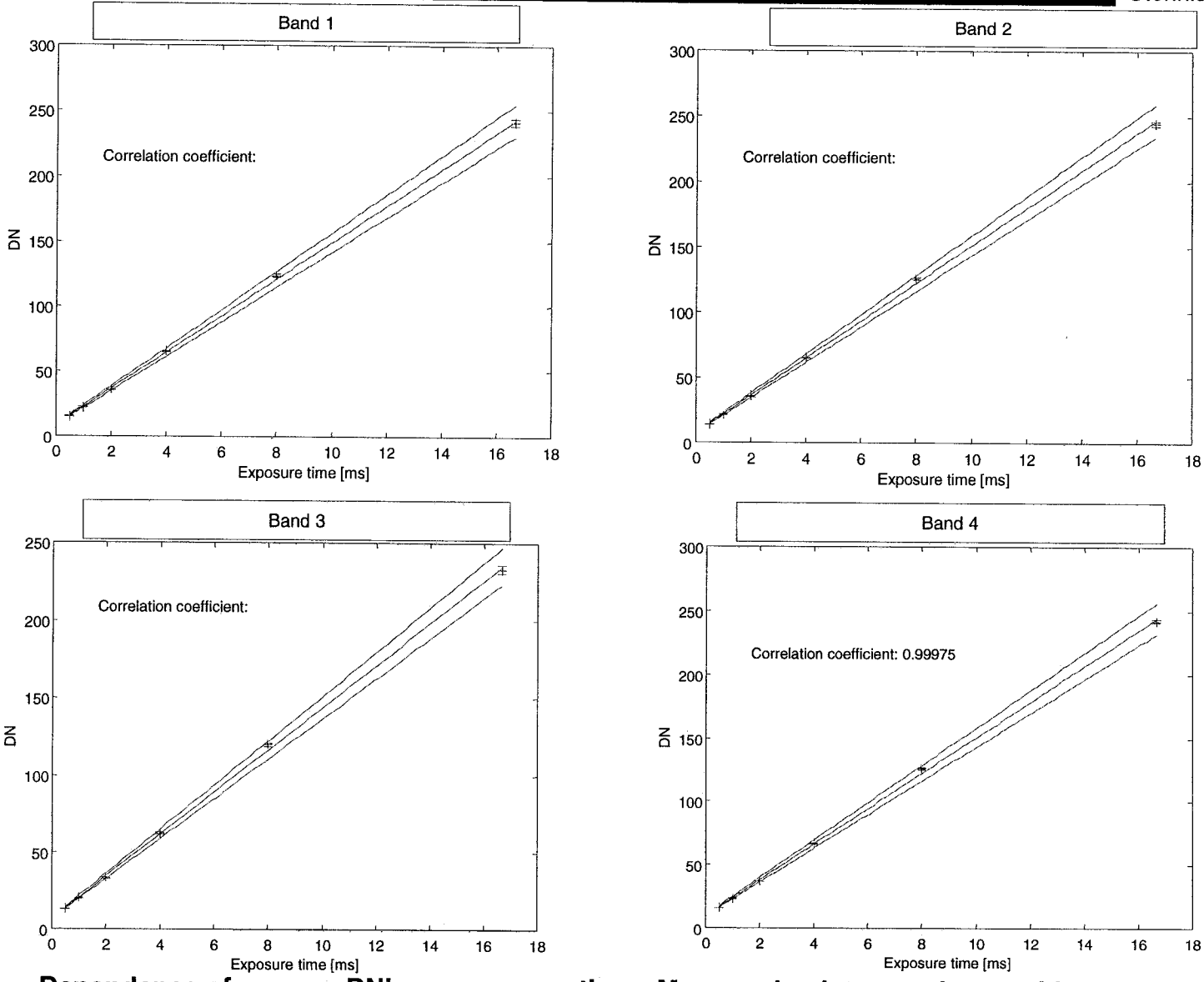
Radiometric, signal-to-noise, and linearity test setup

Radiometric Characterization: Dark Frame Analysis



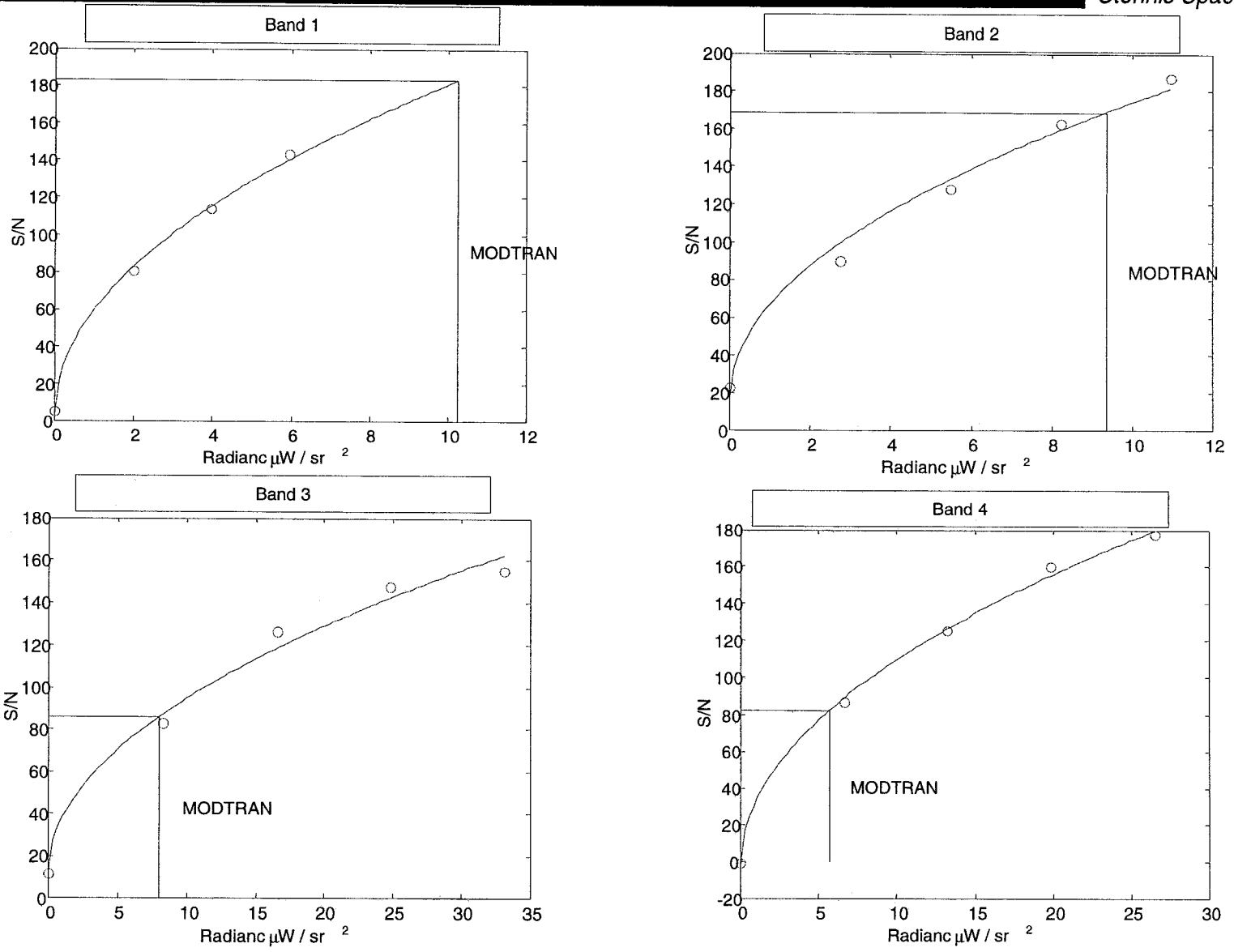
Histograms of dark count numbers

Radiometric Characterization



Dependence of average DN's on exposure time. Measured points are shown with error bars. Solid lines show linear interpolation between the points. Dash lines show the 5% tolerance

Signal-to-Noise

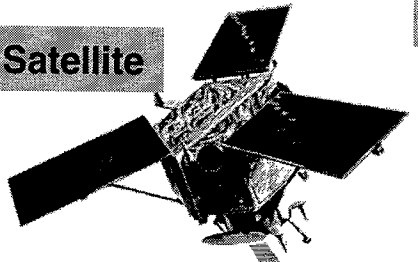


Temporal signal-to-noise ratios. Measured points are shown with circles, dash lines only connect the points, and the long-dash lines show the MODTRAN-generated radiance.

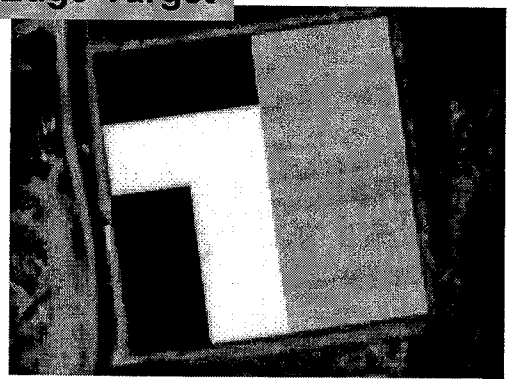
In-Flight Characterization

Spatial Characterization

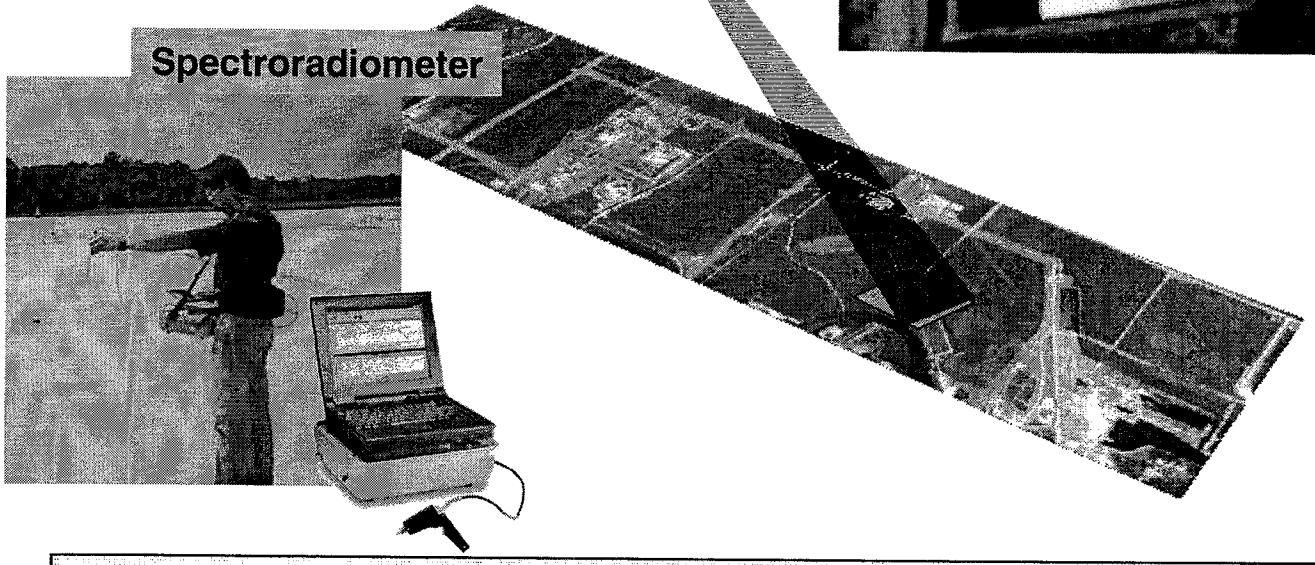
Commercial Satellite



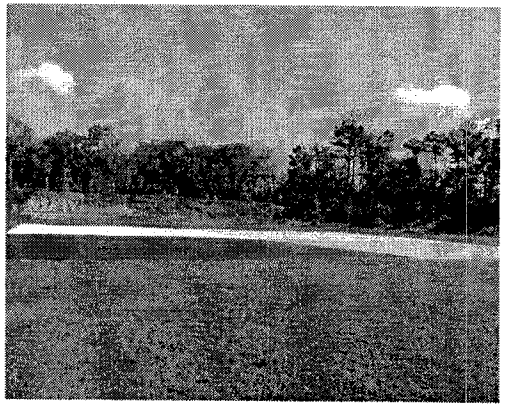
Edge-Target



Spectroradiometer



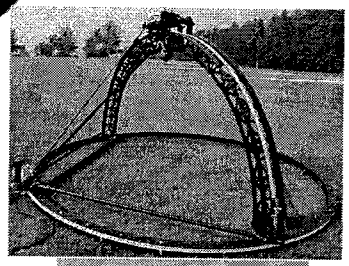
Tarps



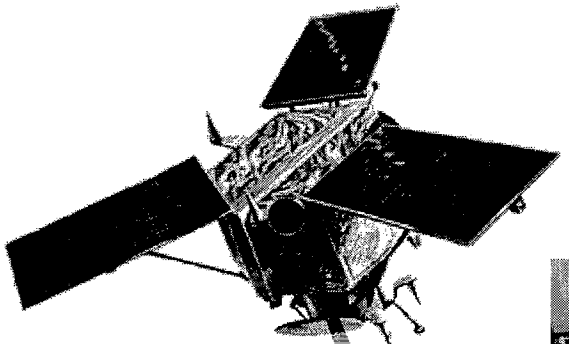
Method: Utilize edge targets (tarps, SSC concrete edge target or other man-made features such as painted runways or buildings) and ground reflectance measurements (spectroradiometer) to determine the edge response of remote sensing systems.

Radiometric Characterization

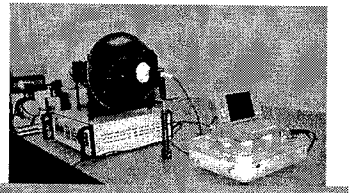
Stennis Space Center



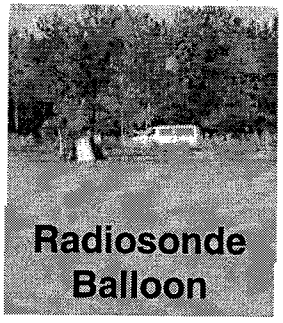
Goniometer



Commercial Satellite

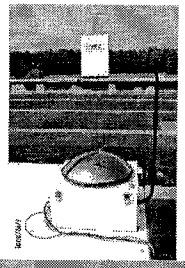


Integrating Sphere

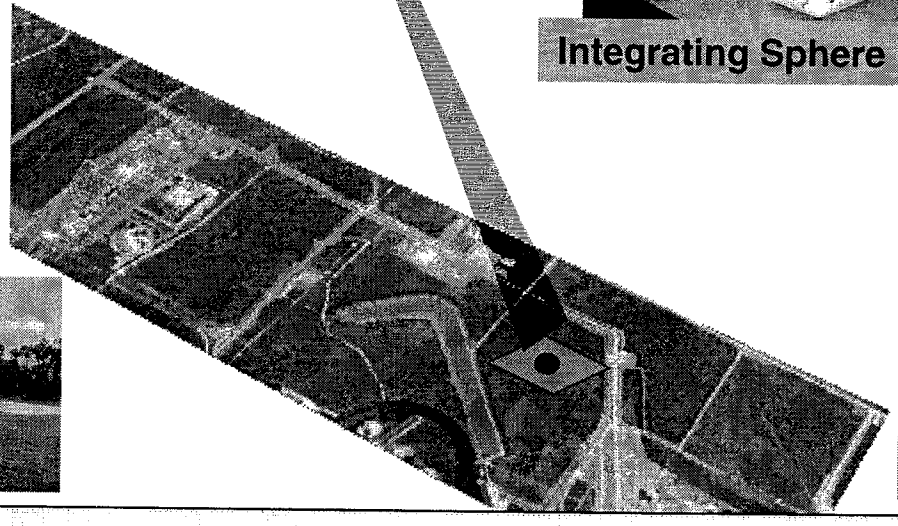


Radiosonde Balloon

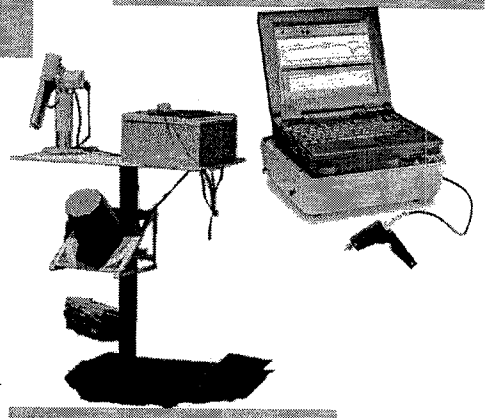
Spectroradiometer



Full Sky Imager



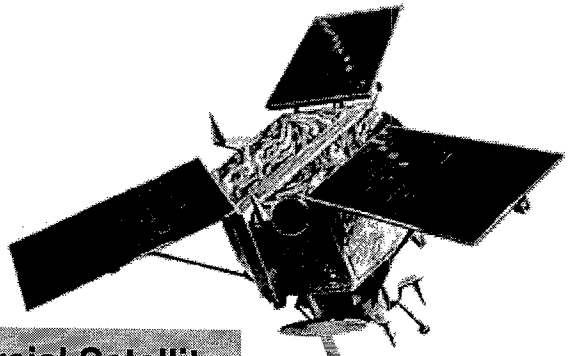
Tarps



Sun Photometer

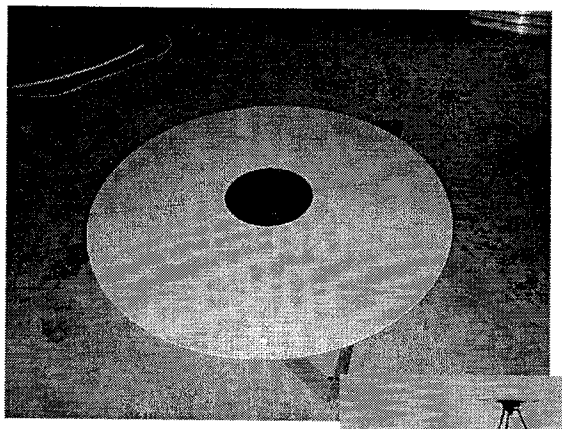
Method: Utilize ground reflectance measurements (Spectroradiometer) and atmospheric measurements (Sun Photometer & Radiosonde) to determine radiometric accuracy of remote sensing systems.

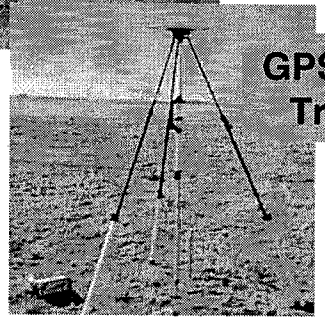
Geometric Characterization



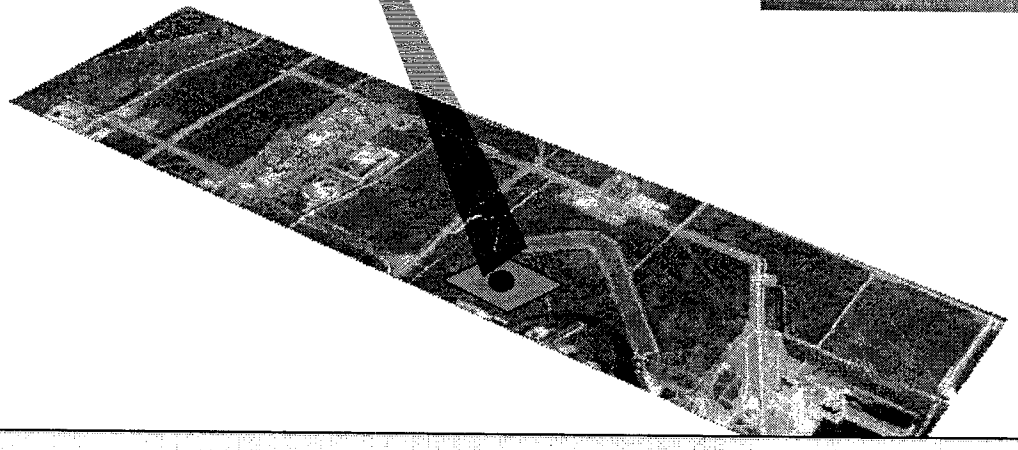
Commercial Satellite

Geodetic Targets

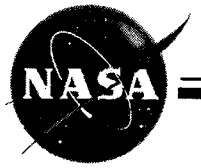




GPS Instrument
Trimble 4000



Method: Utilize geodetic targets and GPS instrumentation to determine the geo-positional accuracy of remote sensing systems.



Summary

- **Characterization of digital camera systems is important for supporting digital imagery guidelines**
- **Specifications are characterized in the lab and/or the field**
  - Laboratory characterization is critical for optimizing and defining performance
  - In-flight characterization is necessary for an end-to-end system test

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